

# A PROCESS AND SYSTEM FOR ESTIMATING THE POWER CONSUMPTION OF DIGITAL CIRCUITS AND A COMPUTER PROGRAM PRODUCT THEREFOR

## BACKGROUND OF THE INVENTION

### Field of the Invention

5                   The present invention relates to the estimation of power consumption of digital circuits, in particular circuits described at the register-transfer level (RTL) or at the gate level.

### Description of Related Art

10                   Estimation of power consumption of circuits described at the register-transfer level or at the gate level usually envisages software simulation of the design in different contexts. This simulation is extremely burdensome in terms of execution time, and moreover must be repeated as many times as possible in order to obtain significant estimates.

15                   For a general review on the subject, useful reference may be made to the texts Synopsys "Power Products References Manual" - V2000.5 and SENTÉ', "Watt Watcher Tutorial", as well as to the work by Hsu, Shen, and Lin, "A Mixed-level Power Estimator for CMOS Circuits Using Pattern Compaction Techniques", Proc. of APPCAS '96.

20                   Current-generation VLSI circuits may reach a size of a few million gates. This entails a wide use of resources for design verification.

                  The verification methodologies currently in use involve simulation of one or more representations of the circuit in order to verify the correctness of the latter from different standpoints, two of which are its functionality and estimation of power consumption.

25                   The representations of the circuit may be at different levels of abstraction.

The representations at a high level of abstraction present the basic drawback deriving from their intrinsic modest detail.

The lower the level of abstraction, the more burdensome the simulation (in terms of CPU, memory, time, etc.) on account of the larger amount of information that has  
5 to be processed in order to achieve greater detail.

The RTL and gate-level descriptions already mentioned previously constitute representations that are currently more widely used. The former is at a higher level of abstraction than the latter. For the verification of a design, the starting point is normally the one in which it is necessary (or at least desirable) to carry out a functional  
10 simulation of the netlist, in particular at a gate level.

This solution leads, however, to exceeding the resources available (memory, CPU, time, etc.) in terms of capacity of the simulator, until the situation rapidly becomes unsustainable when (as ever more frequently occurs) an analysis of power consumption becomes necessary.

15 The reason lies in the fact that, even more than the functional verification, power consumption is strictly linked to the context in which the circuit operates.

A significant example is given by a microprocessor engaged in performing a number of different programs: the same itself may present extremely different patterns of behavior from the power-consumption standpoint (it will suffice to mention standby states  
20 or massive-computation states), with values that differ even by several orders of magnitude.

The only way to obtain acceptable estimates is to simulate the different operational conditions at the lowest possible level of abstraction. Of course, since the sizes of the circuits are such as not to enable simulation at the transistor level, the problem must  
25 be dealt with at the RT level or at the gate level.

Currently, the estimation of power consumption of digital circuits based on simulation techniques is organized in two steps:

extraction of information on the switching activity of the circuit, *i.e.*, on the number of switches between high logic states and low logic states of the outputs of the gates making up the circuit; and

5 estimation of power consumption via dedicated software, starting from the above-mentioned information.

Basically, the extraction technique consists in adding (via linking) to the simulator a set of procedures (*i.e.*, software functions), which, during simulation (at the RT level or at the gate level) access the data and possibly process them and store them in a format usable by the estimator.

10 This is done by means of the program-language interface (PLI) of commercially available simulators, or else by means of programs of conversion of the waveforms plotted in files containing the switching activity.

This approach, however, introduces a further burden for the simulator, in particular when working at the gate level (which is the only one able to guarantee  
15 satisfactory accuracy in absolute terms).

Consequently, even if solutions are available which are potentially able to perform simulation of circuits that may even be made up of as many as several million gates, the software simulation times required for completing this estimation often exceed the lifetimes of the design itself.

## 20 Brief Summary of the Invention

The object of the present invention is therefore to provide a solution for the estimation of power consumption of digital circuits (such as circuits described at the RT level or at the gate level) that is able to overcome the drawbacks outlined previously.

In accordance with the present invention, the above object is achieved  
25 thanks to a process having the characteristics specifically referred to in the ensuing claims.

The invention can be implemented both in the form of a process or method and in the form of a corresponding system.

The latter may be advantageously configured either in the form of a processing unit of a dedicated type (such as a processor or a microprocessor) directly associated to the emulator, or in the form of a general-purpose digital computer which, appropriately programmed, implements the above-mentioned process.

5           The invention consequently also relates to the corresponding computer program product, available on a medium, such as a disk or some other type of storage device and/or a product which may be downloaded from a telematic network and which, once loaded and run on a computer of the kind referred to, enables implementation of the process according to the invention.

10           The solution according to the invention realizes automatic modifications to the design which do not alter the original functionality of the latter (even less so at the level of the terminals), but which, by means of the addition of emulated hardware, enables *in situ* monitoring of the behavior (in practice the output) of each logic gate at each instant of time.

15           The data collected (in real time) are stored for possible post-processing.

In particular, the solution according to the invention does not give rise to a specific test modality, which means that the circuit does not require a particular set of stimuli or a particular configuration.

20           Essentially, the solution according to the invention is based on the use of hardware emulators (which enable a considerable increase in performance, even by several orders of magnitude) in which the design is mapped by modifying the library cells making up the netlists in order to acquire, during emulation, sufficient information for estimation of power consumption. The higher level of performance of the emulators moreover makes it possible to perform a large number of simulations of the same circuit in the most widely  
25   varying conditions.

In this connection, it should be noted that the emulators currently available (see, for example, "Celaro User's and Reference Manuals", Version 2.3\_2, February 2000) do not envisage extraction of information on the switching activity of the circuit, that is, on

the number of switches between the high logic state and low logic state of the networks making up the circuit itself.

The solution according to the invention consequently introduces a method which is alternative to the methods so far known for obtaining the information necessary  
5 for power estimation, involving the use of an emulator. The said solution makes automatic modifications to the design which are altogether transparent to the user, enabling collection (in real time) of sufficient data for making a reliable and complete estimate of power consumption.

#### Brief Description of the Several Views of the Drawing(S)

10 The invention will now be described, purely by way of non-limiting example, with reference to the attached drawings, in which:

Figure 1 illustrates a generic logic gate of a circuit to which the solution according to the invention can be applied; and

15 Figure 2 illustrates the possible application of the solution according to the invention to the logic gate represented in Figure 1.

#### Detailed Description of a Preferred Exemplary Embodiment of the Invention

In what follows, the principles underlying the solution according to the invention will be illustrated in detail.

20 For reasons of clarity, reference will be made to simulations at the gate level, but the same concepts are applicable indifferently also to simulations at the RT level or at a higher level. Consequently, the scope of the present invention must in no way be considered limited to digital circuits described at the RT level or at the gate level.

In Figure 1, the reference G designates any cell whatsoever of a digital circuit described, for example, at the gate level.

25 In general terms, the cell G has a certain number of inputs a, b, c (which may be any number whatsoever, from 1 to n).

According to the values assumed over time by the said inputs, the cell G performs a certain switching activity on its own output x.

The information required for estimating power consumption (namely, the information to be passed on to an estimator) is:

5           a time interval (possibly coinciding with the entire duration of the simulation) on which the estimation is to be made;

          for each node of the netlist, the number of transitions performed during the said time interval; this value is generally referred to as *toggle count*; and

          for each node of the netlist, the fraction of time in which the state is stable  
10 (logic 1 or 0) within the interval defined previously; this value, which can be expressed as a percentage, is referred to as “static probability”.

          In the embodiment currently preferred, the invention is essentially based on the solution illustrated in Figure 2, and envisages associating, to each (standard) library cell making up the design, an element (RTL block or gate-level block) that is able to perform  
15 the second operation and the third operation described previously, *i.e.*, the recording of the number of transitions performed during the estimation time interval, and the fraction of time during which the state is stable within the aforesaid interval.

          In particular, the association may be made at an output pin of the cell G, as in the case of the example herein illustrated. The association may be (also or alternatively)  
20 made at other pins.

          In any case, the combination formed by this new block, designated by B, together with the original cell G may be simply viewed as a new cell having the same inputs (a, b, and c) and the same outputs (x) as the previous cell, which is functionally equivalent (at the external terminals) to the original cell.

25           The resulting cell (original cell G + block B) can finally be included in a library to be used in the compiling phase in the same way as for the original cells. The said library is generated in semi-automatic mode only once and may be re-used for any design mapped in the same logic library.

Data acquisition may be controlled by hardware events monitored by logic analyzers which are active on the emulator and which enable and disable processing of the data in the presence of particular events. This makes it possible, for example, to estimate power only in the execution of a particular portion of code performed by a microcontroller,  
5 by monitoring the Instruction Pointer Register.

The foregoing takes place according to known criteria, at present adopted in currently used emulators (see, for example, the document on emulation previously quoted); consequently, a detailed description of the above modality is altogether superfluous herein.

Since the prerogative of emulators is that of performing the simulation at the  
10 speed allowed by the hardware, the introduction of blocks, such as the block designated by B in Figure 2, does not entail a significant burden in terms of emulation times.

The greater complexity of the new cell has an effective bearing on the capacity of the emulator, in so far as it actually reduces the maximum number of gates that can be emulated (this limitation being due to the physical capacity of the emulator itself).  
15 This, on the other hand, does not constitute too stringent a constraint in that there is no need for extracting all the items of information in one and the same simulation.

Any partitioning technique may in fact be used for selecting sets of homogeneous cells or hierarchical blocks of the design during processing.

The very high ratio (corresponding to several orders of magnitude) between  
20 the speed of an emulator and that of a typical simulator leaves wide margins for the exploitation of multiple simulations.

One of the major advantages afforded by the proposed solution as compared to traditional software solutions lies in its applicability to circuits of arbitrary sizes to be simulated for a sequence of arbitrary inputs, with the achievement of considerable  
25 advantages also in terms of simplicity of implementation (cell library to be created only once) and of transparency for the end user.

During emulation, it is necessary to access the information stored in the blocks B added to the library cells. This access may be obtained by means of proprietary

languages of the emulators which enable inspection of the values of the nets and registers at runtime or via the PLI.

This information can be saved and post-processed to allow reading thereof by the software that performs the *a posteriori* power estimation.

5           The criteria for making the aforesaid power estimation are to be considered known to the prior art (various software products implementing the said function are commercially available), and consequently do not require a detailed description herein, also because the said criteria do not constitute – in themselves – a subject of the present invention.

10           The solution according to the invention makes it possible to handle power estimation also in those cases which cannot handled by means of software simulation.

The said solution can be easily generalized to all transformations conceivable for a library cell by means of the addition of a hardware block that performs a certain function based upon the monitoring of the outputs (or inputs) of the original cell.

15           An additional hardware block, such as the block B, does not modify the functionality of the cell itself in regard to the emulated design, but enables new information to be extracted from a simulation, the only requirement being that of implementing the desired function in the hardware.

20           In the case in question, this is an annotated event count stored in registers which can be accessed at runtime, but various other applications of the same methodology are conceivable.

In particular, the solution according to the invention makes it possible to perform power estimation in digital circuits described at the RT level or at the gate level (but, as has been seen, also at levels other than these), providing a solution in which the  
25           transformations necessary for the design are automatic and do not affect design functionality.

The information extracted can be stored at runtime and is sufficient for power estimation performed with commercially available software products.



Of course, without prejudice to the principle of the invention, the details of construction and the embodiments may vary widely with respect to what is described and illustrated herein, without thereby departing from the scope of the present invention as defined in the attached claims.